U.S. DEPARTMENT OF COMMERCE
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PB-260 211

RADIUM-226 AND RADON-222 CONCENTRATIONS IN CENTRAL FLORIDA GROUND WATERS

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
CINCINNATI, OHIO

JANUARY 1966

002147

253060

PB 260 211

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January 1966

Physical and Engineering Sciences Section
Technical Advisory and Investigations Branch
Division of Technical Services
Federal Water Pollution Control Administration
U. S. Department of the Interior

December 1967

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INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No. PB-260 211
4. Title and Subtitle Radium-226 and Radon-222 Concentrations in Central Florida Ground Waters			5. Report Date Jan 66 6.
7. Author(s)			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Federal Water Pollution Control Administration, Cincinnati, Ohio. Technical Advisory and Investigations Branch.			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address			13. Type of Report & Period Covered 14.

15. Supplementary Notes

16. Abstracts

Phosphate deposits from photphate fertilizer plants are considered to be a potential low-grade uranium ore; therefore, the uranium concentration in the phosphate-bearing formations is much higher than the natural abundance for all rocks. All phosphate-ore formations are older than one million years, and since uranium is considered to be syngenetic, radium is expected to be present in equilibrium amounts with the uranium. High radium concentrations have been found in both the finished fertilizer and the waste waters in ponds adjacent to the plants. Disposal of liquid wastes directly to the environment may be an immediate hazard and leaching of solid-waste spoil piles may be a long-term supply of radium pollution.

17. Key Words and Document Analysis. 17a. Descriptors

17b. Identifiers/Open-Ended Terms

Florida
*Phosphate fertilizer industry
Water pollution
*Radioactive contaminants
Radioactive waste disposal
Solid wastes
Ground water
Liquid wastes

17c. COSATI Field/Group 13B

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 37
	20. Security Class (This Page UNCLASSIFIED	22. Price

Radium-226 and Radon-222 Concentrations in Central Florida Ground Waters

INTRODUCTION

The Physical and Engineering Sciences Section, Technical Advisory and Investigations Branch, FWPCA, was requested by the Florida State Board of Health to assist them in assessing the radium-226 and radon-222 concentrations in central Florida ground waters, especially those areas around the phosphate fertilizer plants.

The phosphate deposits are considered to be a potential low-grade uranium ore, hence, the uranium concentration in the phosphate-bearing formations is much higher than the natural abundance for all rocks. Additionally, all phosphate-ore formations are older than one million years, and since the uranium is considered to be syngenetic, radium is expected to be present in equilibrium amounts with the uranium.

High radium concentrations have been found in both the finished fertilizer and the waste waters in ponds adjacent to the plants. Processing of the phosphate ore is expected to partition the uranium and radium with the radium being concentrated in the waste products and the uranium enriched in the phosphate product. Sampling and analysis have not been made to confirm this supposition. However, disposal of liquid wastes directly to the environment may be an immediate hazard and leaching of solid-waste spoil piles may be a long-term supply of radium pollution.

Ground-water contamination is possible in Polk County and other areas of central Florida. Most of the area is underlain by a surficial cover of thin beds of sands, gravels, clay, and marl of Pliocene to Recent age. Underlying these younger beds is the Bone Valley Formation and the Hawthorn Formation from which it was derived. Both are phosphoric but only the Bone Valley contains commercially minable phosphate ore. The Hawthorn Formation is a confining layer for the artesian water in the "principal artesian aquifer" of central Florida. In this area the top of the aquifer is the Tampa Limestone; this formation and succeeding older formations to as much as 1,500 feet below the land surface produce copious amounts of fresh ground water. Recharge to the artesian aquifer is in areas north of Polk County where the aquifer beds are at or near the surface. In Polk County local recharge occurs where sinkholes extend from the surface through the Hawthorn Formation to the aquifer. It is through such sinkholes that radium polluted water may enter the artesian aquifer, either by direct discharge into a sinkhole or by surface runoff or subsurface migration to a sinkhole. Radium pollution that has been incorporated in the ground-water phase may be discharged to the marine environment by surface and submarine springs. Many large springs have been noted to the west and south of Polk County on land and off-shore in the Gulf.

During the period January 10 - 21, 1966, a number of ground-water samples were collected in the central Florida area for radiochemical and inorganic chemical analyses. The area covered in this ground-water sampling extended in a north-south direction from Groveland to Arcadia

and in an east-west direction from Kissimmee to Tampa. Samples were collected from the following counties: De Soto, Hardee, Highlands, Hillsborough, Lake, Manatee, Orange, Osceola, Pasco, and Polk. Figure 1 shows the general survey area and sample collection points.

Table I presents a summary of the various types of samples collected and a breakdown of the 80 private wells which were sampled. Of the 105 individual wells sampled, depth was not obtained on 29 of them. Depth of the remaining wells ranged from 15 feet to 1480 feet. Approximately 1350 people were using water from the 80 private wells sampled and 157,300 people were using the municipal wells sampled.

FIELD COLLECTION AND LABORATORY ANALYSIS PROCEDURES

As it was desired to analyze all samples collected for radon-222, special collection procedures were employed to ensure that this isotope remained in solution. This was done in the following manner. The faucet at the well or sampling point was turned on and allowed to run slowly for a short time. A one-quart polyethylene bottle was filled to overflowing, the bottle squeezed slightly while full and a screw cap tightened and sealed with black plastic tape. In this manner a slight negative pressure existed inside the bottle and any leakage was into rather than out of the water, thus ensuring minimum or no loss of radon from the sample. In addition to the one-quart sample, two one-gallon samples were collected at each sampling point. The latter provided sufficient sample for detailed radiochemical and inorganic chemical analyses.

Upon receipt of samples in the laboratory, a volume of approximately 20 ml was transferred from the quarts to a tared evacuated radon

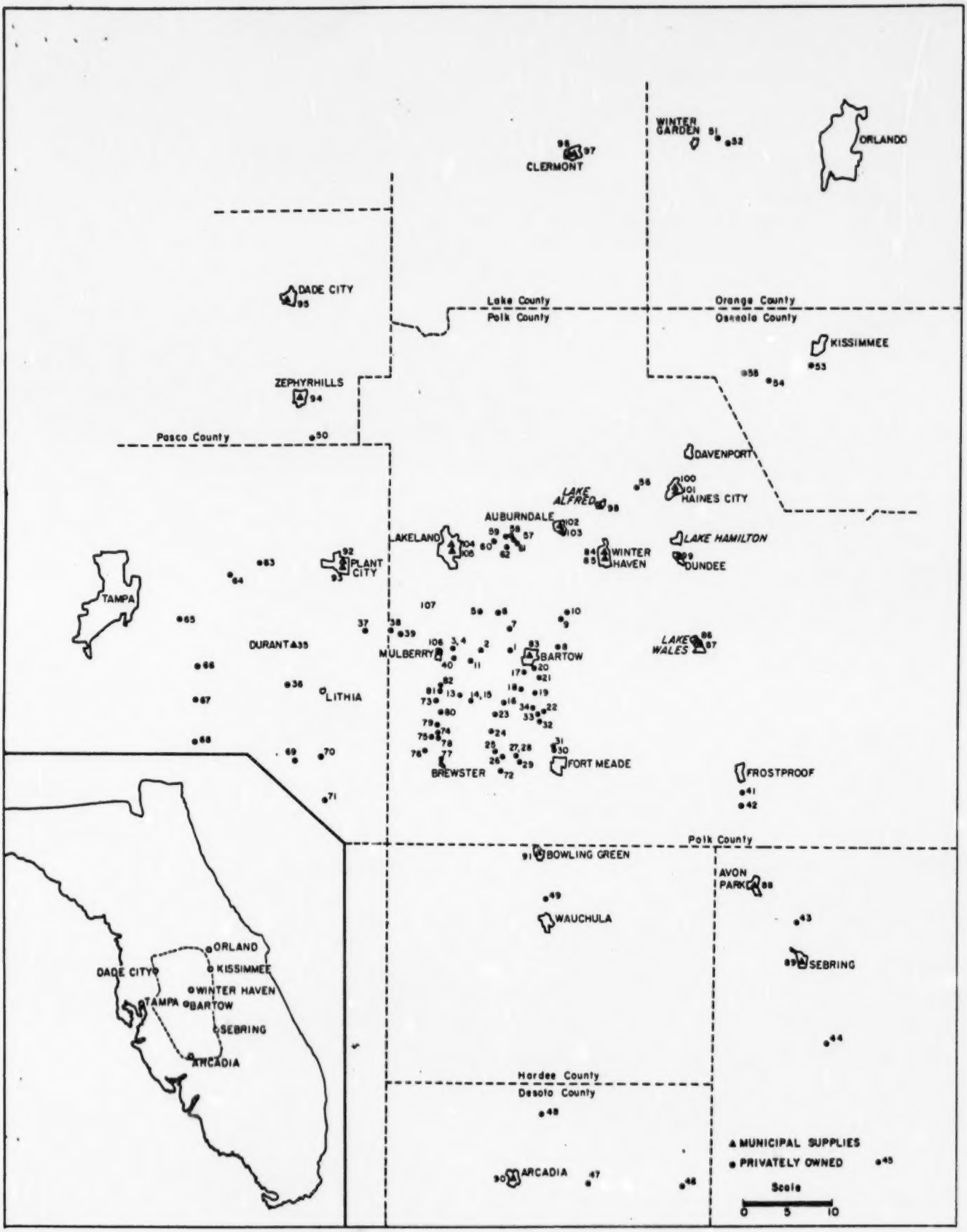

Figure I. GENERAL SURVEY AREA FLORIDA GROUND WATERS

Table I

Summary of Types of Samples Collected

25	Municipal Well Supplies
80	Privately Owned Wells
64	Domestic Use Only
6	Domestic plus Industrial Use
4	Domestic plus Other Uses
2	Domestic plus Irrigation
4	Industrial Use Only
1	Thermal Spring
1	Natural Well
2	River Waters
2	Industrial Waste Waters

bubbler which is shown in Figure 2. The bubbler was then weighed to obtain a volume and the radon subsequently stripped from solution and transferred to an alpha sensitive counting chamber by means of passing aged compressed air through the sample. The scintillation cell and the deemanation assemoly are shown in Figures 3 and 4. The remaining water in the one-quart bottle was filtered through 0.5 micron membrane filters, acidified, and placed aside for subsequent radium-226 determination.

A number of the samples were selected for detailed radiochemical and inorganic chemical analyses.

Radon-222 and Radium-226 Concentrations

Table II presents a percentile summary of the radon-222 and

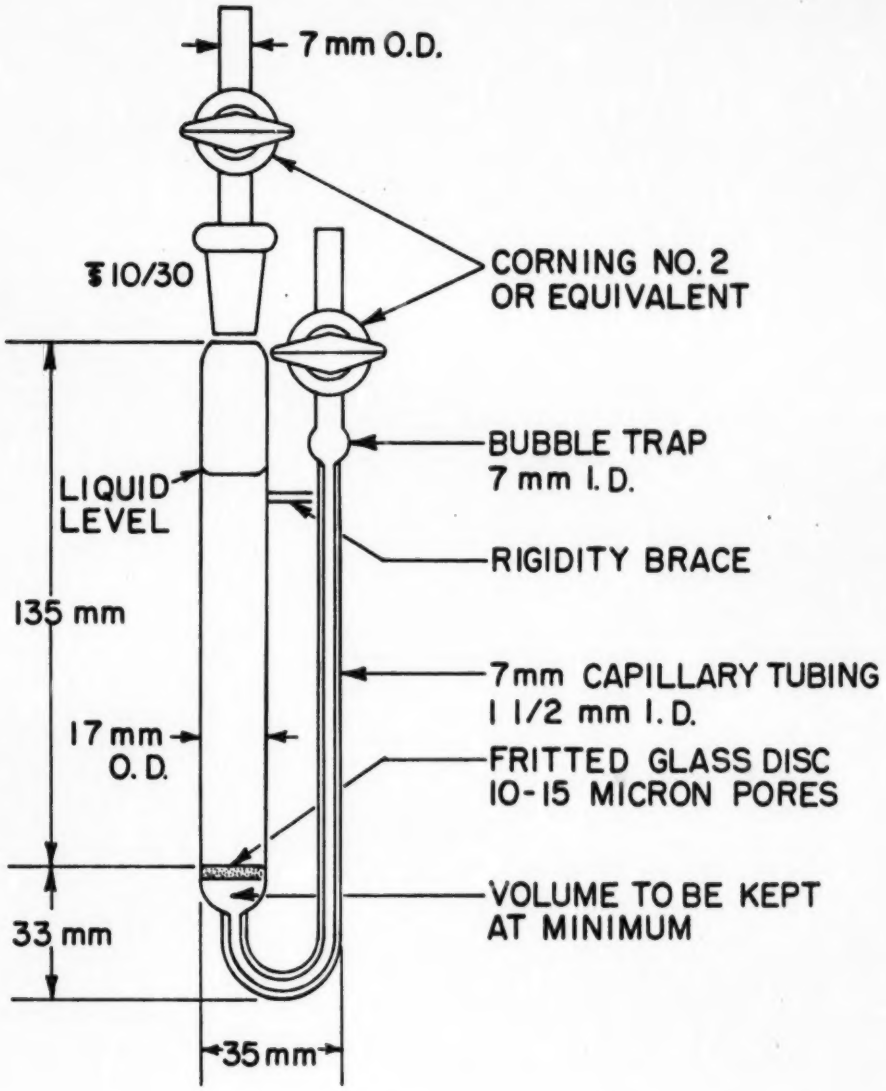

Figure 2. RADON BUBBLER

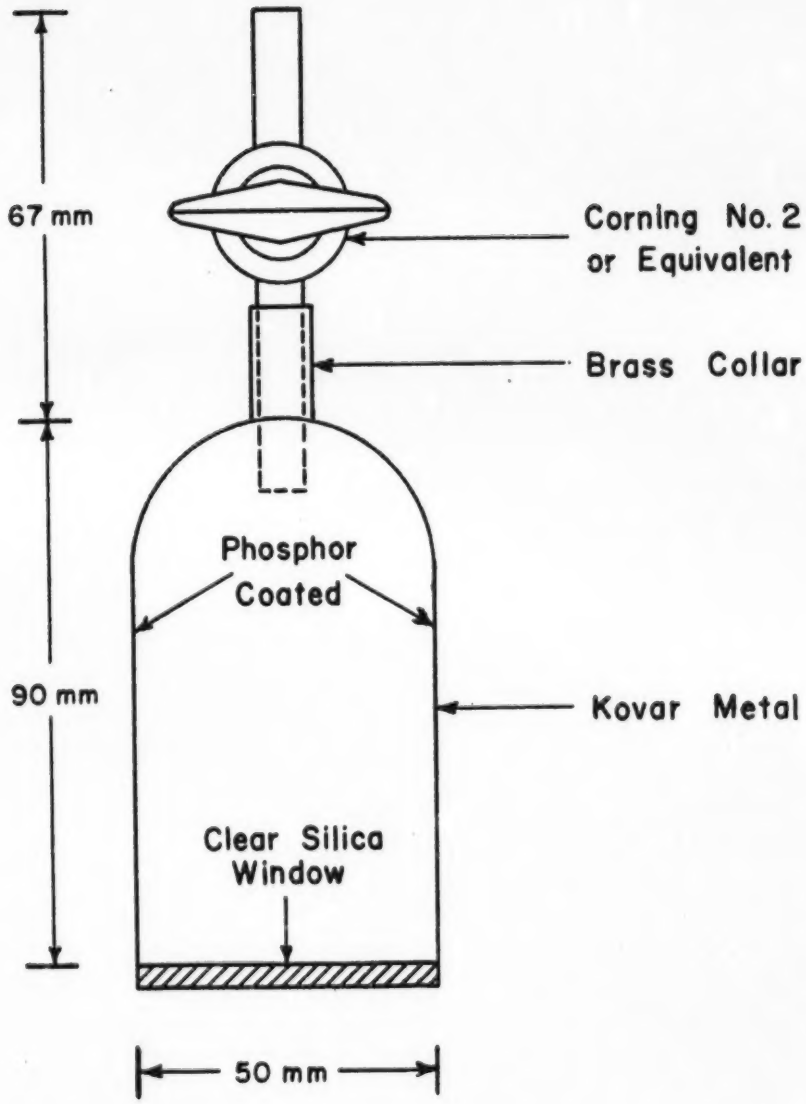

Figure 3. Scintillation Cell

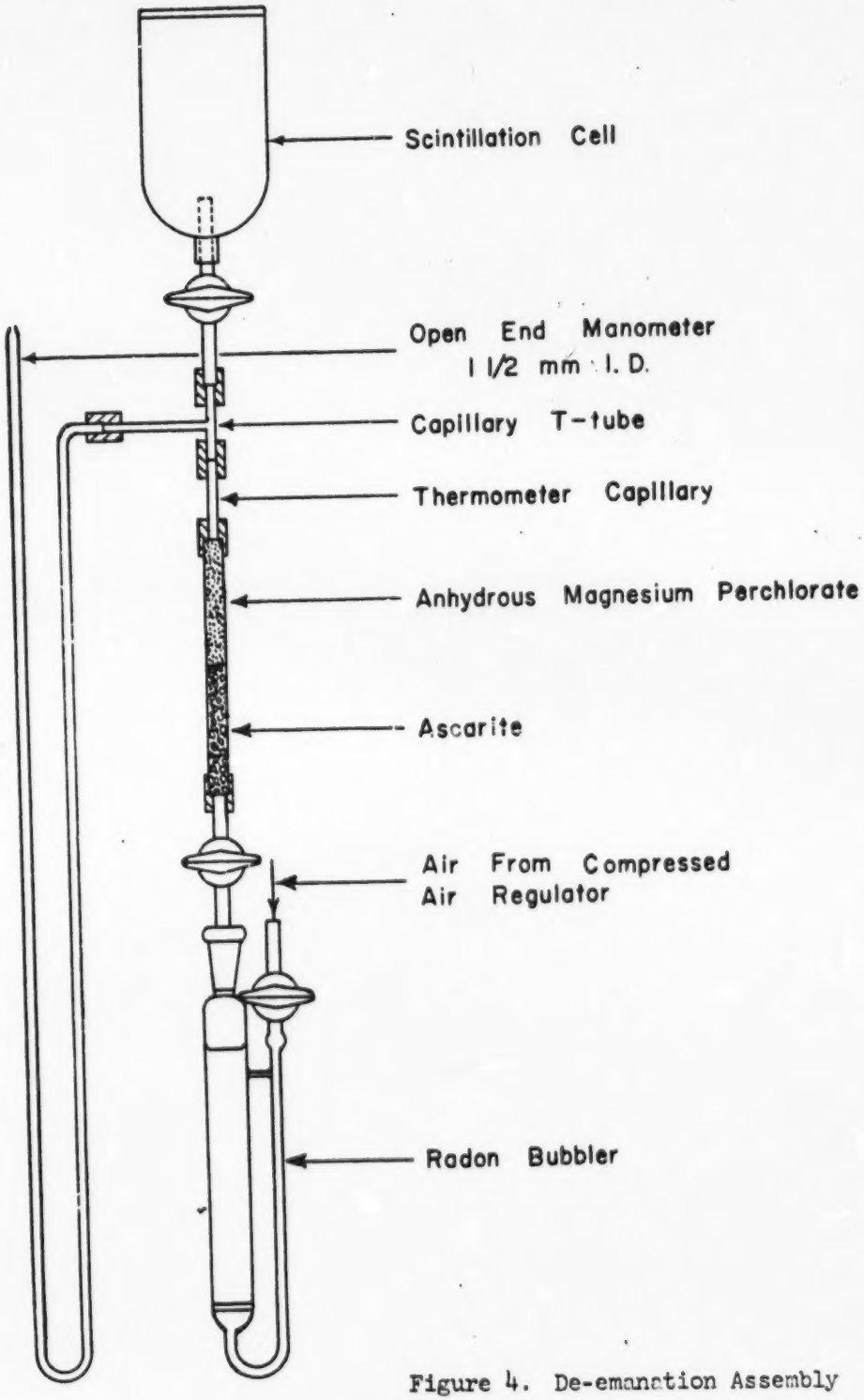

Figure 4. De-emanation Assembly

Table II

Summary of Radon-222 and Radium-226 Concentrations (pc/l) in Central Florida Ground Waters

105 Drilled Wells	Radon	Radium
90% samples	< 8430	< 4.6
75%	< 4160	< 2.4
50%	< 1860	< 1.2
25%	< 260	< 0.5
RANGE OF CONCENTRATION	23 - 46,600	0.0 - 76
80 Private Wells		
90% samples	< 9460	< 4.6
75%	< 4190	< 3.9
50%	< 2780	< 1.4
25%	< 970	< 0.5
RANGE OF CONCENTRATION	23 - 46,600	0.0 - 76
25 Municipal Wells		
RANGE OF CONCENTRATION	35 - 720	0.0 - 4.1

radium-226 concentrations found in the well water samples. Table III presents a tabulation of municipal well supplies with information on sampling site, depth of well, radon-222, radium-226, uranium, thorium, lead-210, and polonium-210 concentrations. Table IV is a summary of the 80 privately owned wells. Table V is a summary of radon and radium concentrations in several miscellaneous samples which were collected. Tables VI and VII present the inorganic chemical analyses from a selected number of stations for municipal and private water supplies, respectively. All radon-222 concentrations have been corrected to time of sample collection.

Of the 105 well samples collected, 60 privately owned wells were located in the central phosphate valley area. For purposes of this report, this is considered to be the area bounded by Range 22 East (R22E), Range 27 East (R27E), Township 27 South (T27S), and Township 33 South (T33S). The average radon concentration of the 60 samples in this area was 4950 pc/l with a range of 76 to 46,600 pc/l. The average radon concentration for the 20 privately owned wells outside of this area was 1,100 pc/l, with a range of 23 to 5,830 pc/l.

INTERPRETATION OF DATA

The interpretation of the data is limited as the study was first designed as a reconnaissance of the radon and radium concentrations in water supplies in and around the phosphate mining and processing areas. Thus the study was intended to be more heuristic than comprehensive. However, a few conclusions can be drawn from the data with reasonable accuracy.

At first glance of the data, there seems to be no correlation between the radon and radium concentration. Any obvious correlation

Table III

Municipal Well Supplies - Central Florida

Sample Number	Municipal Supply	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (µg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
83	Bartow Well No. 3 (RAW)	650	260	1.6	-	-	-	-		
	Bartow (Treated) - Aeration, Filtration, Chlorination		80	1.4	-	-	-	-		
84	Winter Haven Wells 1 and 2 (RAW)	1 - 593 2 - 816	20	0.67	-	-	-	-		
85	Winter Haven Wells 3 and 4 (RAW)	3 - 648 4 - 640	95	0.58	1.2	0.12	0.0	0.0	2.7	2.7
86	Lake Wales Well 1, Market St. Plant (RAW)	1022	60	0.76	-	-	0.2	0.1	3.3	8.2
87	Lake Wales Well 1, Grove Ave. Plant (RAW)	1063	35	0.47	-	-	-	-		
88	Avon Park (RAW)		560	0.98	0.7	0.11	0.5	0.1	3.7	3.7
89	Sebring Franklin St. Well (RAW)	1480	140	-	0.7	0.11	0.2	0.1	0.4	3.8
90	Arcadia Well 1 (RAW)	495	480	3.3	0.9	0.52	0.6	0.1	4.9	24
	Arcadia (Treated) Aeration, Chlorination		210	2.5	-	-	-	-		

(continued)

Table III (continued)

Municipal Well Supplies - Central Florida

Sample Number	Municipal Supply	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (µg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
91	Bowling Green at Water Tank		260	2.7	0.9	0.15	0.3	0.3	2.4	11
92	Plant City Well 3	750	150	0.77	-	-	-	-		
93	Plant City Well 2	368	360	0.00	1.2	0.06	0.1	0.0		
94	Zephyrhills	425	360	0.31	1.2	0.00	0.3	0.0	2.9	-
95	Dade City Well 1	150	305	0.00	-	-	-	-		
96	Clermont South Well	525	600	0.39	-	-	-	-		
97	Clermont Highland Well	550	720	0.29	1.8	0.04	0.1	0.0	0.8	
98	Lake Alfred Well 4 (RAW)	560	220	4.1	-	-	-	-		
	Lake Alfred (Treated) Aeration, Chlorination		50	1.8	-	-	-	-		
99	Dundee Well at City Park		560	0.0	-	-	0.0	0.0	0.7	4.3
100	Haines City Well 7	800	125	0.74	-	-	-	-		
101	Haines City Well 8	565	115	0.73	-	-	-	-		
102	Auburndale, Tampa St. Well	616	110	0.50	-	-	-	-		
103	Auburndale, Water Plant Well		85	0.53	-	-	-	-		

(continued)

Table III (continued)

Municipal Well Supplies - Central Florida

Sample Number	Municipal Supply	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
104	Lakeland Well - 9 N. Florida Ave.	865	160	0.80	-	-	0.1	0.1		
105	Lakeland Well 22	891	260	0.84	-	-	-	-		
106	Mulberry Well 1	778	165	0.45	1.4	0.06	0.4	0.1		
107	Medula Recreation Center - North of Mulberry		320	0.23	-	-	-	-		

Table IV

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (µg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
1	H.W. 60 one mile west of Bartow, Polk County	1100	76	0.08						
2	H.W. 60 two miles west of Bartow, Polk County	551	680	1.86						
3 4	Ridge Wood Rod and Gun Club, 3 miles east of Mulberry, Polk County	170	2880	1.71	0.7	0.01	0.0	0.0	12	23
5	H.W. 548 five miles N.E. of Mulberry, Polk County	300	210	0.48						
6	H.W. 540A one-half mile south of Highlands City, Polk County	155	95	0.49						
7	1-1/2 miles north of Bartow, Polk County	200	970	0.43						
8	H.W. 60 two miles east of Bartow, Polk County	-	3060	2.18	1.5	0.74	0.0	0.1	5	27
9	H.W. 17 one and one-half miles south of Airbase, Polk County	-	1030	0.69						

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (µg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
10	H.W. 17 one mile south of Airbase, Polk County	35	3550	4.5	0.9	0.38	0.6	0.1	5	13
11	H.W. 60 two miles east of Mulberry, Polk County	-	3240	0.61						
12	International Minerals Chemical Co. (Bonnie Plant), Polk County	900	860	0.40						
13	0.1 miles east of Bonnie Mine Rd. on Pebbledale Rd., Polk County	60	3890	0.12						
14 15	1/2 mile west of CCA on Pebbledale Rd., Polk County	-	990	2.35						
16	H.W. 640 at Jct. S.R. 555, Polk County	-	18,200	0.21	0.1	0.06	1.2	0.4	0.9	15
17	Bartow, 860 Herner St. Polk County	80	1010	1.19						

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (µg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
18	International Minerals Chemical Co., Noralyn Plant, Polk County	92	8370	2.70	2.2	0.03	0.8	0.2	10	14
19	Homeland Rd. 1-1/2 miles north of Homeland, Polk County	98	4730	4.21						
20	One mile south of Bartow on Homeland Rd., Polk County	200	4160	1.87						
21	H.W. 17. 1-1/2 miles south of Bartow, Polk County	89	4190	1.04						
22	H.W.17. 3 miles south of Bartow, Polk County	160	5600	1.99	1.2	0.00	0.5	0.2	6	10
23	H.W. 555. One mile south of intersection of H.W. 555 and H.W. 640, Polk County	70	46,000	1.89	0.4	0.03	3.4	1.4	2	16
24	Swift Co. East Deep Well, Agricola, Florida, Polk County	800	1750	1.14						

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (µg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
25	Swift Co. well B-3, one mile west of Swift Co., Polk County	1100	2000	1.78	1.4	0.04	0.3	0.0	5	16
26	Minute Maid Co., two miles west of Agricola	-	28,800	49	11	0.37	7.6	1.5	75	194
27 28	Off Bevis Rd. two miles west of Ft. Meade, Polk County	105	5780	5.22						
29	Bevis Rd., 2-1/2 miles west of Ft. Meade, Polk County	-	22,700	76	4.2	0.58	3.7	0.8	97	144
30	H.W. 17, 1/2 mile north of Ft. Meade, Polk County	97	9750	0.21						
31	H.W. 17, 1/2 mile north of Ft. Meade, Polk County	187	10,850	5.13						
32	Homeland, Polk County	105	4480	2.68						
33	Homeland, Polk County	-	4130	2.41						
34	Homeland, Polk County	88	2310	2.15						

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (µg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
35	Durant Section - Durant Rd. at Turkey Creek, Hillsborough County	201	1860	1.41						
36	Intersection of H.W. 640 and Runyon Rd., Hillsborough County	90	2490	1.11						
37	H.W. 60, 6 miles west of Mulberry, Hillsborough County	150	3040	-						
38	S.R. 60 and Coronet Rd., 4-1/2 miles west of Mulberry, Polk County	200	6270	3.84	2.4	0.08	0.6	0.1	10	-
39	H.W. 60, 3 miles west of Mulberry, Polk County	96	3350	0.16	-	-	0.3	0.1	1.0	0.0
40	2 miles east of Mulberry, Polk County	96	4260	0.02	-	-	0.2	0.1	0	0
41*	Kelly Rd. and H.W. 27A, 1 mile south of Frost Proof, Polk County	105	32	3.9						

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
42*	H.W. 27A, 2 miles south of Frost Proof, Polk County	37	25	1.2						
43*	H.W. 27A, 3 miles north of Sebring, Highlands County	300	3830	2.3	-	-	0.2	0.2	5	13
44*	H.W. 27, 7 miles south of Sebring, Highlands County	69	23	1.42						
45*	Grassy Lake, one mile north of intersection of H.W. 27 and H.W. 70, Highlands County	46	76	5.4						
46*	H.W. 60, 2.5 miles west of Desoto-Highlands County line	-	1250	0.67						
47*	Intersection of H.W. 70 and H.W. 760 east of Arcadia, Desoto County	268	3500	8.4	0.9	0.08	0.4	0.1	20	49
48*	Brownville, Desoto County	-	1100	1.22						

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (µg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
49	H.W. 17, one mile north of Wanchula, Hardee County	85	4040	0.44	0.8	0.09	0.1	0.1	2	13
50*	H.W. 39, at Crystal Springs, Pasco County	36	470	0.82						
51*	H.W. 50, 2 miles east of Winter Garden, Orange County	-	365	0.49						
52*	H.W. 439S, 1.4 miles south of H.W. 50, Orange County	-	2780	2.33	0.1	0.04	0.0	0.1	5	5
53*	H.W. 17, 2 miles south of Kissimmee, Osceola County	60 - 70	153	-						
54*	H.W. 17, 5 miles south of Kissimmee, Osceola County	90 - 115	870	2.17						
55*	H.W. 17, south of Kissimmee, Osceola County	74	1350	0.43						
56	1.5 miles west of Haines City off H.W. 92, Polk Co.	200	2340	3.9						

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
57	3.5 miles east of Lakeland off H.W. 92, Polk County	162	1860	2.7						
58	3.5 miles east of Lakeland off H.W. 92, Polk County	53	2610	0.75						
59	2.5 miles east of Lakeland off H.W. 92, Polk County	150	6210	-						
60	H.W. 542, one mile east of Lakeland, Polk County	27	10,000	1.20	1.4	0.04	0.7	0.4	1.9	0
61	Intersection of Fields Rd. and H.W. 542 east of Lakeland, Polk County	287	3810	1.89						
62	Old Auburndale Rd. 4 miles east of Lakeland, Polk County	120	2410	3.58						
63*	H.W. 92, 1.75 miles west of Plant City, Hillsborough County	134	550	0.03						
64*	H.W. 92, 2 miles east of H.W. 579, Hillsborough County	150	240	0.02						

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
65*	Intersection of H.W. 301 and Palm River Rd., Hillsborough County	80	2020	0.46						
66*	River View,, Hillsborough County	-	750	0.30						
67*	H.W. 301, .75 mile south of Alafia River Bridge, Hillsborough County	-	784	1.93						
68*	H.W. 301, 2.5 miles south of Riverview, Hillsborough County	96	630	1.73						
69	H.W. 672, 2 miles west of Picnic, Hillsborough County	187	3400	0.32	1.4	0.04	0.2	0.1	0.4	4
70	Intersection of H.W. 672 and H.W. 39 at Picnic, Hillsborough County	-	7650	0.28	0.8	0.01	0.6	0.1	6	0
71	Intersection of H.W. 674 and H.W. 39 at Ft. Lonesome, Hillsborough Co.	-	2650	0.33					0.3	0

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
72	H.W. 630, 1.7 miles west of Armour Ft. Meade, Polk County	143	11,300	7.41	1.6	0.04	1.3	0.3	12	-
73	4 miles south of Mulberry on H.W. 37, Polk County	200	5120	2.14	1.4	0.11	0.3	0.2	-	-
74	Bradley Jct., 6.5 miles south of Mulberry, Polk County	183	7330	3.90						
75	Bradley Jct., 7 miles south of Mulberry, Polk County	-	2070	0.11	1.4	0.03	0.4	0.1		
76	One mile south of Bradley Jct., Polk County	80 - 90	9460	4.32						
77	Intersection of new and old H.W. 37, Polk County	-	3300	1.31						
78	Old H.W. 37 south into Bradley Jct., Polk Co.	15	7600	19						

(continued)

Table IV (continued)

Privately Owned Wells - Central Florida

Sample Number	Location	Depth of Well (ft)	Rn-222 (pc/l)	Ra-226 (pc/l)	U (μg/l)	α Th (pc/l)	Pb-210 (pc/l)	Po-210 (pc/l)	Gross Alpha (pc/l)	Gross Beta (pc/l)
79	Bradley Jct., Polk Co.	-	1480	1.31						
80	Rolling Mills, Polk County	-	6550	2.3	1.4	0.04	0.7	0.3		
81	Oak Terrace, Polk Co.	-	8680	4.6						
82	Oak Terrace, Polk Co.	-	8430	0.0						

* Considered outside of area.

Table V

Miscellaneous Samples

Sample Description	Rn-222 (pc/l)	Ra-226 (pc/l)
Lithia Springs - Thermal Springs	2360	0.65
Alafia River - State Route 640 at Bridge (State Sampling Point A4)	45	0.21
American Cyanimid Slimes Pond Water	12	0.17
Natural Well - Highway 640 at Bridge over South Fork Alafia River	300	2.05
International Minerals Corporation Gypsum Pond Water (at Spillway)	240	112.90
Peace River at Saddle Creek	20	0.65

Table VI

Inorganic Chemical Analyses, ppm - Municipal Supplies

Sample Number	pH	Alkalinity as $CaCO_3$	Nitrate Nitrogen	Total Hardness	Conductivity *	Total Phosphate	Sulfate	Total Solids	Fluorides
85	7.7	110	0	120	120	0.03	10	184	0
88	7.6	78	0	88	75	0.15	2.0	98	0
93	7.6	168	0	174	165	0.29	3.0	114	0.4
94	7.5	108	1.6	109	120	0.26	5.0	324	0
97	7.4	78	1.2	88	96	0.41	3.0	144	0
99	7.9	104	-	112	110	0.23	4.5	164	0.3

* μ mhos at 25°C

Table VI

Inorganic Chemical Analyses, ppm - Privately Owned Wells

Sample Number	pH	Alkalinity as $CaCO_3$	Nitrate Nitrogen	Total Hardness	Conductivity *	Total Phosphate	Sulfate	Total Solids	Fluorides
4	7.7	82	0	91	83	0.07	4.5	128	0.5
8	7.4	246	0	260	230	0.17	10	324	0.7
10	4.1	0	7.4	60	110	0.08	4.5	150	0.1
16	6.3	18	0	26	46	2.8	15	90	0.5
18	7.8	78	0	83	83	0.12	2	112	0.4
22	7.5	136	2.6	164	175	0.44	72	242	0.3
23	6.3	20	0	23	41	2.6	15	120	0.3
25	7.8	224	0	224	220	0.03	4.5	334	1.0
26	4.7	4	26.0	369	520	0.28	220	952	1.2
29	5.1	4	16.0	179	215	0	120	368	1.2
38	7.9	166	0	179	160	0.13	1.5	220	0.1
39	6.9	44	4.0	57	60	0.50	5.5	124	0
40	7.4	184	0	8	200	0.13	3	294	0.3
43	7.1	78	0	60	60	0.40	2.0	108	0

(continued)

Table VII (continued)

Inorganic Chemical Analyses, ppm - Privately Owned Wells

Sample Number	pH	Alkalinity as $CaCO_3$	Nitrate Nitrogen	Total Hardness	Conductivity *	Total Phosphate	Sulfate	Total Solids	Fluorides
47	7.8	172	0	200	215	0.13	4.5	124	1.7
49	7.6	124	0	75	102	0.61	1.5	184	0.4
52	7.5	120	0	112	120	0.41	2.0	98	0.2
60	7.8	188	-	200	200	0.16	4.5	270	0.2
69	7.7	148	0	143	135	0.09	7.5	168	0.3
70	7.9	98	0	117	90	0.15	4.0	106	0.6
71	6.7	42	0	29	48	4.10	5.0	96	0.6
72	7.8	178	0	169	155	0.27	3.0	238	0.4

* μ mhos at 25°C

is masked by the extreme ranges of the concentrations, particularly the radon concentration. However, if the radon and radium concentrations are ranked in a decreasing order, and a Spearman's rank-order correlation P (Rho) calculated, an observed value of 0.347 for 100 pairs of data (private and municipal water supplies) is obtained. At the $\alpha = 0.001$ critical level for N = 100, the upper limit due to chance is 0.321. Thus, it can be seen from this test that there is a definite, although slight, correlation between the radon and radium levels.

Secondly, are the observed radon and radium levels in untreated water supplies outside the active mining area different from the observed levels within the area? Again a casual glance does not confirm or deny this.

If, however, we again rank the sample values collectively in a decreasing order (N_1 to N_T) and apply the Wilcoxon equation to test whether or not the two groups are from the same population or two distinct populations, a Z-statistic can be calculated from the equation:

$$Z = \frac{\Sigma R n_1 - \frac{n_1(N_T + 1)}{2}}{\sqrt{\frac{n_1 n_2 (N_T + 1)}{12}}}$$

where n_1 = Number of samples outside the area

n_2 = Number of samples inside the area

N_T = $n_1 + n_2$

ΣRn_1 = Summation of the rank position of the samples outside the area,

we observe a $Z_{Ra^{226}} = 1.3$; $Z_{Rn^{222}} = 3.7$.

Comparing these calculated values to a Z-statistic table, it can be shown that the Ra^{226} concentrations in the water samples between the two areas are not significantly different at the 95% confidence level ($\alpha = 0.05$). This, however, does not imply that the Ra^{226} concentrations in the earth are statistically equivalent. On the contrary, since the Rn^{222} concentrations in the water samples are significantly different at the 95% and even at the 99.9% confidence level and since radon, an inert gas, is readily soluble in water whereas its precursor, Ra^{226}, is probably so chemically bound as to be relatively insoluble, it can be concluded that higher Ra^{226} deposits coincide with enriched phosphate deposits.

The Federal Radiation Council (FRC) has defined ranges for total daily Ra^{226} intake and recommended countermeasures. These are:

Range I -	0-2 pc	Periodic confirmatory surveillance
Range II -	2-20 pc	Quantitative surveillance and routine control
Range III -	20-200 pc	Evaluation and application of additional control measures.

Assuming a 2-liter daily intake of water, a water supply whose Ra^{226} concentration is 10 pc/l would place an individual at the upper limit of Range II, disallowing any other ingestion of Ra^{226} from other sources (food, air). The Public Health Service Drinking Water Standard has been set at a value of 3 pc/l.

Reviewing the data, two municipal water supplies are above the 3 pc/l level but below 10 pc/l. In the case of the privately owned wells, 12 wells are greater than 3 pc/l and less than 10 pc/l; three wells are greater than 10 pc/l (19, 49, and 76 pc/l).

It should be pointed out that at present there is no accepted standard for Rn^{222} in water. A number of workers have addressed themselves to the question and have suggested possible maximum permissible concentrations for Rn^{222} in water.

The Maine State Department of Health and Welfare, after reviewing several articles on this subject, established tentative guidelines for permissible concentration of radon in water to be used until a firm standard is set. These guidelines are 180,000 pc/l occupational dose, 18,000 pc/l for an individual in the population, and 16,000 pc/l for public water supplies. The above figures are about 10% lower than those suggested by Hursh and co-workers.*

Only four privately owned wells are above this 18,000 pc/l Rn^{222} whereas no municipal wells even approach this figure. Aeration would substantially reduce the radon concentration by approximately 50-75% to within these guidelines as deduced from the data given in Table III, Sample Numbers 83, 90, and 98.

Radon values should be evaluated in terms of sample collection techniques. Radon values for pumped wells probably have little interpretive

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* Hursh, John B., et al. Health Physics, Vol. 11, p. 463-76 (1965).

significance; however, such values may be useful for rapid reconnaissance of many wells over a large area to identify those wells that should be sampled for radium analysis.

At this time, it should be noted that the concentration of Ra^{226} in Sample 26 is 49 pc/l. This is of prime interest insofar as the plant utilizing this supply is in the food processing business. The extent of the incorporation of this water into a consumable commodity should be investigated. If the water comes into direct contact with or is incorporated into the marketable product, the supply should be suitably treated and continuously monitored or an alternate water source developed. Suitable treatment would be lime-soda softening or demineralization.

In regard to the chemical constituents of the water, none of the determined elements exceeds the limits set forth in the Public Health Service Drinking Water Standards.

Recommendations

As a result of the study, the following recommendations are submitted:

1. That the recommendations set forth by the FRC be implemented; that is, all well waters used for domestic consumption whose Ra^{226} concentrations range from 1-10 pc/l be routinely monitored. Monthly monitoring of these wells is recommended, with possible reduction to quarterly intervals after trending or stability is established. For all domestic well supplies containing Ra^{226} in excess of 10 pc/l, corrective action should be taken to decrease the level to within Range II, and hopefully to within Range I of the FRC. In the case of industrial or municipal supplies, such

corrective action could take the form of either lime-soda or ion exchange softening (split or complete treatment). Private supplies will probably be limited by economic considerations to the utilization of the "household" type water softeners. These supplies on which corrective treatment measures are instituted should be initially monitored on a weekly (7-day composite) basis to establish the effectiveness of the treatment process. Subsequent monitoring might be decreased to weekly composites analyzed on a quarterly or monthly basis.

2. Wells previously showing high radium concentrations should be resampled and efforts made to identify the aquifer supplying water to them.

3. In some areas of Florida, ground waters contain excessive radium with respect to parent uranium. An effort should be made to determine if a natural disequilibrium exists in the "principal artesian aquifer" and if so, the degree. Determination of the natural background disequilibrium will permit identification of water to which excess radium has been added from outside sources.

4. The characteristics of the effluents from the fertilizer industry should be determined and a radium and uranium balance should be done for plant operations. Surface-water courses near the plants and ground water for all municipal wells down the hydraulic gradient from the plant should be sampled and analyzed also for radium and uranium.

Summary

Ra^{226} and Rn^{222} concentrations in water supplies, both municipal and private, were determined in and around the active phosphate mining area. A correlation between radon and radium concentration does exist but is yet empirically undefined. The radon concentrations in well water outside the phosphate mining area are lower than those within the area. Recommendations for further study have been incorporated.